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EXPLANATIONS

OF

TIME-KEEPERS,

CONSTRUCTED BY

MR. THOMAS EARNSHAW

AND THE LATE

MR. JOHN ARNOLD.

PUBLISHED

BY ORDER OF THE COMMISSIONERS OF LONGITUDE.

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1806.

PRICE FIVE SHILLINGS.

PREFACE.

Two time-keepers, constructed by Mr. Thomas Earnshaw, were tried, three several times, at the Royal Observatory, by order of the Commissioners of Longitude, for a twelvemonth or more at a time, between 1798 and 1802, as candidates for some of the great rewards held out by the Act of Parliament of the 14th of his present Majesty; but were adjudged not to have gone within any of the limits prescribed by the Act, and therefore not thought proper to be sent to sea, to undergo the subsequent trial required by the Act. However, as they appeared to have gone with sufficient exactness, in the two last trials, to be of considerable use in navigation, the Commissioners, on the 3d and 17th of March 1803, resolved unanimously to grant to Mr. Earnshaw the sum of £2500 in addition to £500 which they had given him before.

On the 23d of March 1804 Messrs. Earnshaw and Arnold were desired to prepare models and drawings, with descriptions of their respective escapements; and they produced their models at the following board on June 7th. And on December 6th following they were required to give in a full account in writing, with drawings of the principles and constructions of their respective time-keepers, and methods of adjusting them; the Board having come to a resolution to grant an equal reward to Mr. Arnold as to Mr. Earnshaw, for their respective improvements on time-keepers.

On December 12th, 1805, the communications required of Messrs. Earnshaw and Arnold being completed, they were sworn to the same. The Commissioners then signed a letter to the Commis-

sioners of the Navy for paying £2500 to Mr. Earnshaw, and £1678 to Mr. Arnold, making up to each, with what they had received before, the sum of £3000.

The Board, at their meeting on March 6th last, ordered the explanations and drawings of the time-keepers to be printed and published; which, it cannot be doubted, will make the manufacture of them more easy, common, and exact.

NEVIL MASKELYNE,
ASTRONOMER ROYAL.

Greenwich, May 5, 1806.

EXPLANATION

OF

TIME-KEEPERS,

CONSTRUCTED BY

T. EARNSHAW.

THREE OF THEM HAVING BEEN TRIED UNDER THE PRESENT ACT OF PARLIAMENT.

Delivered to the Board of Longitude, March 7th, 1805.

EXPLANATION, &c.

THE Escapement is detached, and the best of all others for equal measure of time: because the Vibrations of the Ballance are free from the friction of the Wheels, in the manner I have made it, except about one-twelfth part of the Circle whilst the scape Wheel acts on the pallet to keep up the motion of the Ballance, which is done with considerable more power and less friction than by any other Escapement, because it receives but one blow from the Wheel, whilst other Escapements receive two; and has an equal advantage of the same quickness of train, and when the Impulse is given to the Ballance by the Wheel it is given in a similar direction and not in opposition, as most Escapements are which produce recoil. This is clearly proved by its causing a heavier Ballance to vibrate to a greater distance. This Escapement should be made in the following manner.

The pivots of the Ballance Axis should be the size of the verge-pivots of a good common sized pocket Watch, and of the following shape, which will greatly add to their strength, the extreme end, or acting part only being straight; the jewell hole should be as shallow as possible, so as not to endanger cutting the pivot, and the part of action of the hole made quite back, with only a very shallow chamfer behind to retain the oil; deep holes are very bad, for when the oil becomes glutinous, it will make the pivots stick, so as to prevent the Ballance from its usual Vibration. The pallet should be half the diameter of the Wheel, or a little larger, for if smaller, or one-fourth the diameter, as Arnold's is, the Wheel will then have too much action on it, which will increase friction most considerably, and like-

wise cause the Ballance to swing so much farther to clear the Wheel; consequently a Check in the motion of the Ballance may stop the Watch; and this, in my opinion, may cause time-keepers, so constructed, to stop. The face of the pallet should run in a line of equal distance between the centre of the pallet and its extremity, and not in a right line to its centre, as this causes an increase of friction, and a loss of that power which is obtained by the Wheel acting on the extremity of the pallet: This is clearly proved by time, by the holes worn by the points of teeth in all pallets that run in a line to the centre. The Scape Wheel teeth should form the same direction as the face of the pallet, under cut for the said purpose of avoiding friction, and maintaining the power, and for safe locking. The points of the Wheel teeth must not be rounded off, but left as sharp as possible. The pivots of the scape Wheel are to be a very little larger than the Ballance pivots.

The Wheel is locked by a spring instead of a Detent with pivots, as the French have made them, for those pivots must have oil, and when the oil thickens then the spring of the pivot Detents is so affected by it as to prevent the Detent from falling into the Wheel quick enough; the consequence of this is irregular time and stoppage of the Watch; and if ever such a watch went well for Twelve Months, Chance must have had by far the most hand in it.

When the Spring is planted on the side of the Wheel, as in my Escapements, the part on which the Wheel rests should be a little short of a right angle, so that the Wheel may have a tendency to draw the Spring into it, for if sloped the other way, or beyond a right angle, it will have a tendency to push the Spring out; in that case the Wheel will have liberty to run: the Wheel should take no more hold on the Spring than just sufficient to stop it; for if more, friction will be increased. The small return spring should be as thin as possible at the end fastened to the other spring, but at the outer end a little thicker; the spring should be planted down as close to the wheel as to be just free of it. The discharging pallet about one-third, or near one-half the size of the large or main pallet, the face of it in a right line to the

centre, the back of it a little rounding and off from the centre. Great care must be used in taking off the edges of this discharging piece, to make it round to prevent cutting the spring, nor can it be made too thin so it does not cut; the end of it nearest the Ballance should be a little more out from the Centre of the Ballance axis than the lower part of it towards the Potence, for counteracting the natural tendency of the spring downwards from the pressure of the scape wheel; and that part of the spring on which the Wheel rests should be sloped a little down to give the wheel a tendency to force it up, to counteract the natural Inclination the wheel has to draw it down by its pressure on it.

The Ballance is to be made of the best steel, and turned from its own Centre to its proper size, then put it into a Crucible with as much of the best brass as when melted will cover it. The brass melted will adhere to the steel (for if any other Metal is used by way of solder, that watch cannot go well), then turn it to its proper thickness, and hollow it out so as to leave the steel rim about the thickness of a Repeating spring to a small sized repeating Watch, turn the brass to twice or near three times that thickness of steel, cross it out with only one arm straight across the centre, and at each end of the arm fix two screws opposite to each other through the rim of the Ballance to regulate the watch to time, the diameter of the heads of these screws about equal to the thickness of the Ballance, a little more or less is not material. The Compensation Weights should be made of the best brass and well hammered, and a groove turn'd to let the rim of Ballance into it, and this should be cut into fourteen equal parts by a wheel Engine, then you will have seven pair of pieces of equal size and weight; two of these pieces being screwed on the rim of the Ballance at equal distances will produce an Equilibrium, a Ballance in the full sense of the word, equal in all its parts. In making Ballances great care should be taken that they get no bruises or bendings, for if they get a bruise on one side so as to indent the Metal, that part will be less affected by Heat and Cold than the other parts which have not

received the same violence to close their pores; consequently the Ballances made by Mr. Arnold by rule of Thumb, Bending, Hammering, and Filing, without one single truth about them, must to the poorest Mechanick be inconsistent in the extreme, as no worse method can be taken and can only go well by some error compensating for others; for should there be one stroke of the Hammer on the Compensation piece on the one side of the Ballance more than on that on the other, Heat and Cold on them will produce different effects; and if the two Metals which compose the Compensation for Heat and Cold be soldered together, it is still worse, as then the Compensation will be composed of three Metals instead of two, three acting bodies, as follows—The brass has a tendency with every change in the atmosphere to move one way; the steel has a tendency to move the same way, but not so rapid as the brass; but the force of the brass warps the steel with it, here then they might act pleasantly together; but the middle, or soldering Metal, between the brass and steel, having a greater tendency to rapid motion than the other two, and being confined between them, will undo that natural easy accordance which they without it would have possess'd, and will act as a third man between two men of equal force, but not so rapid in action as the middle one, warping with him either way his Inclination is to move; and the said natural easy accordance in two metals so necessary to obtain perfection must not be destroyed by a third.

Ballances are likewise spoil'd by bending the Compensation pieces: Bending cracks and destroys the compact body of the Metal. The soldering up those cracks with a Metal very different in expansion to the Metal crack'd is hurtful, nor is it possible to bend the Compensation pieces into a true Circle; in that Case they forming so many parts of different Circles, nothing regular can be produced; and I defy the world to produce a more inconsistent Method of making Expansion Ballances. The mode of making them, as well as the workmanship of most I have seen, are wretched in the extream.

To adjust the Ballance in Heat and Cold—put the Watch into about 85 or 90 degrees of Heat by the common Thermometer, mark down exactly how much it gains or loses in 12 hours, then put it into as severe a cold as you can get for12 hours, and if it gains one minute more in 12 Hours in Cold than in Heat, move the Compensation Weights farther from the Arm of the Ballance about $\frac{1}{8}$th of Inch, and if it gains one Minute more in 12 Hours in Heat than in Cold move the Weights $\frac{1}{8}$ of Inch nearer to the Arm of Ballance, and so on in the like proportion, trying it again and again, till you find the Watch go the same in whatever change of Heat or Cold you put it in.

Much difficulty has fallen to the Lot of Watchmakers in the endeavour to make Timekeepers go nearly the same in the different positions, I have had my share of this, but it is now over; by far the greatest part of this difficulty arises from the Ballance Spring not being properly made. But if the Spring is made, as I shall describe hereafter, you have only to make the Ballance of equal Weight and it will go within a few Seconds per Day in all positions alike, and if it vibrates not more than 1 Circle and a $\frac{1}{4}$, by applying a small matter of Weight to that part of the Ballance which is downward when in the position that it loses most, will correct it with great Accuracy; but if it Vibrates more than 1 Circle and a $\frac{1}{4}$ then it will require the Weight to be above instead of below; and after the Watch has been going a few Months and its Vibration shortens to $1\frac{1}{4}$ Circle, then it will go worse and worse by reason of the Weight being in the wrong place; therefore to avoid this Evil, it is absolutely necessary to confine the Vibrations to $1\frac{1}{4}$ Circle, which will produce the most steady performance. It is common for Watchmakers to adore a Timekeeper when they see it Vibrate a Circle and a half, or more, and form an opinion of its excellence from this only; but I know from experience what would be the consequence, and have been condemn'd, because, when I have seen such Watches I said I saw enough to declare that it would not give very accurate performance.

Ballance Spring. To find out the invisible properties of this appa-

rent Simple part of the Machine, has given much more trouble than all the rest, I despair'd of bringing Timekeepers to the State I have done, and unless those hidden properties are known to Timekeeper Makers, however well they may execute all other parts, they will find their most Sanguine expectations frustrated. I have seen Watch-makers boast of their Timekeepers going well for a Month or two, and from the Knowledge I had of the effects produc'd by the Ballance Spring, I have told them that a month or two more would destroy their hopes: to explain this; the Cylindrical Spring being in all its turns of equal distance from the Centre, in course every turn will be of equal strength, and call'd isochronal, and it has been believ'd that all Vibrations whether long or short would be perform'd in the same time; but this is not true, for if a man is to go four Miles in the same time as he has gone one Mile, he cannot do it with the same power; no, he must have impelling force to quicken his Motion, or he will be four times as long in doing it. Therefore instead of the Spring being equal in all its parts, it must be made to increase in thickness to the outer end, in such proportion as will cause the Ballance when thrown to a greater distance to return so much the quicker to make them equal; by long perseverance I found how to make such Springs, and then I thought I had got all I wish'd for. But cruel Disappointment nearly broke my Heart, for I found I had yet another difficulty to break down, as my Watches with such perfect Springs were continually losing on their rates. What farther to do I knew not, and I own I was nearly if not quite mad. But obstinate in the cause and resolving not to give it up but with Life, Perseverance came once more to my Aid—and with still more unremitting Study, which nearly finish'd me, before I applied the following remedy for the before mentioned Evil, I found, in the course of reasoning on Bodies, that Watch Springs relax and tire like the Human frame, when kept constantly in motion, and this may be proved by the following Experiment: let a Watch, that has been going a few Months, go down, let it be down for a Week or two, or more, then set it going, and if it be a good Time-keeper, so

as not to be affected by the Weather, it will go some seconds per Day faster than it did when it was let down, but it will again lose its quickness in a gradual manner gaining less and less till it comes to its former rate. Therefore finding that isochronal Springs would not do—and likewise having made Springs of such Shape as would render long and short Vibrations equal in time—constantly lose the longer the Watch went, I then made them of such shape as to gain in the short Vibrations about 5 or 6 seconds per Day more than the long ones, this quantity could only be found by long experience, and the way I prov'd this was to try the rate of the Watch with the Ballance Vibrating about $\frac{1}{3}$ of Circle, then tried its rate Vibrating 1 Circle and a $\frac{1}{4}$, and if the short Vibrations go slower than the long ones that Watch will lose on its rate, and if they are Equal, it will likewise lose, but that only from relaxation, and if it gains in the short Vibrations more than 5 or 6 Seconds in 24 Hours it will in the long run gain on its rate, but if not more than that Quantity, and the Time-keeper is perfect in Heat and Cold and every other part, the above properties will render it deserving of the name of a perfect Timekeeper ; and this is a principal cause of my Timekeepers excelling all others, and this is the principal cause of some of my Timekeepers going better than others, though made by me, the Springs of them being made to accord more exactly to the above proportions; and this is the cause which has enabled me to foretell what my Timekeepers would do, which Dr. Maskelyne, Mr. Crosley, and others can testify. The above effect is produced as follows. I find the common relaxation of Ballance Springs to be about 5 or 6 Seconds per Day on their rates in the course of a Year; therefore if the short Vibrations are made by the shape of the Spring to go about that quantity faster than the long ones, and as the Spring relaxes in going by time so the Watch accumulates in dirt and thickening of the oil which shortens the Vibrations, the short ones then being quicker compensated for the Evil of relaxation of the Ballance Spring. From this it is plain, that the causes of error in Timekeepers are not undefined and vague in

their nature, which has been suppos'd; for when it is certain that all causes of error may be over compensated, we cannot despair of finding the Medium, and which may be easily prov'd by examining the going of my Timekeepers. It will there appear that what errors, they are subject to, arise from causes certain and natural, and in course may be corrected by art.

The Detach'd Escapement is a Dead Scape, if properly unlock'd as I have done it, on the outside of the wheel. The unlocking on the inside is improper, being against the whole train of Wheels and causes a recoil. When the wheel is lock'd on the heel of the tooth instead of the extremity; the absurdity of this is too plain to the meanest Mechanick to need any comment; the notches cut by the pallet rubbing on the round face of the Scape Wheel teeth clearly prove how much friction presides there; and such a wheel is much more difficult to make than mine. My size of pallet evidently tends most effectually to prevent watches stopping.

With respect to the preferrence to be given to box above pocket-Timekeepers, I think the former are the best for the following reasons. Every Watchmaker surely knows the Influence of oil. Therefore if oil by its change robs a main Spring of the force of one pound of its power, then a Main Spring of the force of one Ounce must be Sixteen times more affected by it. This is well known by the effect produced by the change of oil on pivot detents, when Time-keepers are made of a large size, merely for the purpose of having a Large and Powerful Main Spring to drag the Works on through all Impediments of oil and dirt; but before this is done it should be considered whether a greater evil is not likely to happen, namely, the Evil of Friction, far greater than that of oil. There is a Happy medium between these two Evils. Whether I have found out that Happy Medium or not, I leave to the Examination of every Impartial man who may Examine my Timekeepers, in which he will not find cuttings and tearings in any part or hardly be able to discover in the oldest of them the least trace or place mark'd on which the Escapement has acted. Thus then my

old Friend Time and Ocular demonstration is sure to fix the wreath with me. It may be said that in avoiding this Evil, Friction, I am subject to the mischief from oil—I trust that the Regularity of going of my Timekeepers knocks down that Argument. There are certain degrees only of force which metals and all other bodies can bear, without tearing each other. As far as the bodies will resist this, go, but no farther—for when you use so much force as to cause the acting Bodies to injure the surfaces of each other, or any one singly, the worst of all Evils in Timekeepers begin to be generated. My Box Timekeepers have nothing like the force of Main Spring of some watches, yet they vibrate quite as far with a Ballance equally Heavy; it is then clear that their force, though so much less, produces all the Advantages, by avoiding friction, without being influenc'd by the oil, as their steady going fully proves. A Pocket Timekeeper may go as well as a Box one, but not generally so, and the good going of them principally depends on the goodness of the oil. I have found oil sometimes turn out so, as to shorten the Vibrations of a Pocket Timekeeper half its usual Quantity, and in a few months more would nearly if not quite have stopped it. This would have had but little Effect on a Box one.

On account of the difficulty of making watches go the same in different positions, gimbols have been introduced; and when properly made, they will have the desired effect.

Explanation *of the Advantages of my* Escapement *over that made by the late Mr.* Arnold.

1st. My Escapement has more Vibration from the same Power than his.

2nd. This is in consequence of the Ballance being more detached than Arnolds, which is of great advantage, having thereby less friction in the action of scape.

3d. Increase of Friction destroys equality of motion, so necessary to determine the Longitude; and as the samc Vibration can be obtained in mine, as in Arnolds, with less power, consequently there cannot be so much friction in mine as in his.

4th. Mr. Arnold's scape with Pallat $\frac{1}{4}$ Diameter of Wheel requires $\frac{1}{3}$ of Circle to clear it, my scape with pallat $\frac{1}{2}$ Diameter of Wheel requires only $\frac{1}{6}$ of Circlc to clear it, which is only half the quantity of action to what Arnolds has, consequently friction is by that means most considerably reduced, and the Causes that would stop Arnolds Watch, would not affect mine, mine, being doubly detached to his.

5th. The causes which, in my opinion, prevent my Time-kcepers from being so subject to stop as Arnold's, are the difference in the shape of the pallet and scape-wheel teeth, and principally in the difference of their sizes; thcse differences in their sizes and shapes have done away that which the Watch-makers before had not the least idea of.

6th. My Scape Wheel is lockcd on its extream point, and unlocks in an easy manner in a similar Circlc with the Whecl. Arnolds is locked on thc heel of the tooth, and nearcr the Centre, and unlocks in opposition to the whole train of wheels, which, in my opinion, are two great disadvantages.

The Truth of the above Observations has been Subscribed to by the following Watch-makers, and signed by them, and sent to the Board of Longitude Dec. 6, 1804, and which has hitherto stood uncontested.

(Signed by) J. WATKINS,
WM. FRODSHAM, JUN.
GEO. JAMISON,
ROB. BEST,
C. J. COPE.

There are Persons who have still the weakness to assert to this Hour that the detents with pivots are better than my contrivance the Spring. To which I answer in the following manner. Those pivots have friction in their action, the Spring has none; the action in pivot-detents requires oil, that oil when it thickens and becomes glutinous robs the tender spring of the pivot-detents of its power, the Wheel then is subject to pass two teeth, and impedes the motion of the Ballance, which frequently stops the watch. The Trade could not follow the plans of Mr. Harrison and Mudge, because of their Complexity, but they have, with tolerable success, followed mine from its simplicity, which accords with the following demands of the Act of Parliament, Provided, "that such Method is generally Practicable and useful."

Therefore, however well their Watches may go, it is doing Honour to and proving the Excellence and Practicability of my inventions.

The best train for Time-keepers is - - -	18,000
Scape Wheel of Pocket ones - - - -	15 teeth
Box ones - - - - - -	13 teeth

Every thing else in my Timekeepers is well known to Watch-makers. I have made and sent about one thousand of them into the world, many of them have been constantly Employed in Conducting the most valuable part of the Commerce of this Country in safety, and preserving his Majesty's Ships and Subjects from Rocks, Sands, and

Lee Shores; and thus, by the Perseverance of my Life to preserve that of others, I have greatly injured my health, and Endangered my own. And if instead of this I had turned my attention to the line of Fashion and Fancy in my Profession, I should have avoided that Evil, and been able to have retired with a handsome Fortune long since.

DESCRIPTION *of the Plates and Parts of* TIME-KEEPER *constructed by* THO. EARNSHAW.

Fig. 1. Plate 1 represents the Time-keeper as together.
Fig. 2. The Pillar plate, from which the Calliper may be taken; *a*, the height of pillars.
Fig. 3. The Barrell and Main Spring, *b* side view of Barrell.
Fig. 4. The Fusee and Great Wheel, with Rochat to keep it going whilst winding up, *c* side view of Fusee.
Fig. 5. Second Wheel and Pinion, *d* side view of second Wheel.
Fig. 6. Third Wheel and Pinion, *e* side view of it.
Fig. 7. Fourth Wheel and pinion, *f* side view of it.

Fig. 1. Plate 2, represent the upper plate, with the Escapement on it, from which the Calliper may be taken. Observe that the Draftsman has not placed the pallet near enough the Wheel; but this is of no consequence, as I have given in to the Board before a very proper and exact draft of the Escapement on a much larger scale, in Plate III, therefore the Escapement is to be understood from that Draft, this only shews the sizes of the different parts.
Fig. 2. Side View of the Scape Spring which locks the wheel.
Fig. 3. One of the Brass Weights to be fix'd on the rim of the Ballance for the Compensation for Heat and Cold—*g* the groove cut in it to receive the rim of the Ballance. The rim of the Ballance is cut through in two places in opposite directions as in plate I, fig. 1, and two of these Weights are to be placed on the Ballance rim at equal Distances as there represented and fastened by a screw as at *h*. These Weights are to be mov'd backwards or forwards on the rim of the Ballance to make the

Watch go faster or slower in Heat, or in Cold, as by trial may be found necessary, and which is explained in page 7.

Fig. 4. Side view of said brass weight, *k* the groove to receive the rim of Ballance, its depth shews the breadth for Ballance rim.

Fig. 5. The Cylindrical Ballance Spring. The only advantage attending the Cylindrical shape is, that it is rather easier made, a saving of about one Hour of time; for if a spring is made as I have described it, in page 8, 9, and 10, it is of no consequence in what shape it is turn'd, whether Cylindrical or Spiral. If the real Body or form of the spring be like the shape of the stem of a feather or common writing quill, it is of no consequence, as I have said before, whether it be turn'd into a Spiral or Cylindrical figure.

OF THE ESCAPEMENT.

THE model, from which the drawings in Plate III. were taken, contains, besides the parts necessary to explain the nature of the Escapement, a box inclosing a spring, which when wound up communicates, by means of some more wheels, a force to the ballance-wheel sufficient, when the ballance is put in motion, to keep it in action for some time. These wheels are contained between two brass plates, fastened together by four upright pillars; the uppermost of these plates is that which is represented by Fig. 1st, where PQRS are the four screws that take into the heads of the four pillars above mentioned, and connect it to the remaining part of the model. The plate PQRS contains, however, the whole of the parts necessary for the present purpose. The side of this plate represented to view, is the undermost when fixed in the model; so that the figure represents this plate as taken off, with the side next to the ballance laid upon a table, and the eye is supposed to be placed perpendicular over it.

In the plate PQRS is an opening, or a piece taken out, represented by TUWXYZ. In this opening, the ballance-wheel ABCD, pallet MSK, and part of the ballance UV are seen. The ballance-wheel is supported by two pieces of brass, ONH, OI; the piece ONH is screwed to the side of the plate nearest to view by a strong screw *t*, and made firm by small pins represented by $\pi\pi\pi\pi\pi\pi$; these pins are called steady pins; they are riveted fast into the supporting piece OH, and take into holes in the plate PQRS, made exactly to fit them. The part ON of this supporting piece is supposed to be raised above the part *t* H by a joint or bend at N; the other supporting piece OI is fastened to the opposite side of the plate; and between these two pieces the ballance-wheel turns freely and steadily in the direction of the

letters ABCD. The small wheel MSK is called the large pallet; it is a cylindrical piece of steel, having a notch or piece cut out of it at *l h r*; against the side of this notch is a square flat piece of ruby, or any hard stone, *hl*, ground and polished very smooth, and fixed fast into the pallet. The cylinder is so placed, with respect to the balance-wheel, that it may not be more than just clear of two adjoining teeth. EF is a long thin spring, which is made fast at one end, by being pinned into a stud, G, and made to bear gently against the head of an adjusting screw *m*: the other end is bent a little into the form of a hook; to this spring there is fixed another very slender spring at *γ*, which projects to a small distance beyond it. This small spring lies on the side of the thick spring nearest to the ballance wheel. The adjusting screw, *m*, takes into a small brass-cock, *α p*, which is screwed fast to the plate PQRS by a strong screw at *p*. Upon the spring EF there is fixed a semi-cylindrical pin, which stands up perpendicular upon it, and of a sufficient length to fall between the teeth of the balance-wheel ABCD. This pin is called the locking-pallet, and is placed on the opposite side of the spring represented to view. Through the centre of the cylindrical pallet MSK, a strong steel axis passes, called the verge; the pallet is made fast to this axis, which also passes through the centre of the balance, and is made fast to it; it has two fine pivots at its extremities, upon which it turns very freely, between two firm supporting pieces of brass, screwed firmly, and made as permanent as possible, by steady pins, to the principal plate PQRS; one of these pieces is represented in the figure by *wy* L; the part *w* is raised above the part *y* L by a bend or joint at *n*; the part *y* L being represented as fixed firm to the plate by the strong screw at *y*. This piece is called the potence, and is exactly similar to the other supporting piece, which is called the cock, that is similarly fixed to the opposite side of the plate and hid from the sight in the figure. A little above the cylindrical pallet MSK (as it appears in the figure) is fixed a small cylindrical piece of steel *i n*, having a small part projecting out at *i*, through which the verge also passes; this is called

the lifting pallet; it fixes upon the verge like a collar, and is made fast by a twist, so as to be set in any position with respect to the large pallet MSK. The balance lying below the plate PQRS, only the part UV is represented to view; the continuation of the position of the circumference, however, is represented by the dotted lines ULHV. The end EG of the long spring EF being made very slender, if a small force be applied at the point *o* to press that end out from the wheel ABCD, it easily yields in that direction, turning as it were upon a center at G; it is also made to slide in a groove made in this stud in such a manner that the end *o* may be placed at any required distance from the center of the verge. Having described the several parts as they appear in the figure, we next come to their connexion or situation with respect to each other. Let the long spring EF be supposed to be so placed that the end of the slender spring $\gamma\, i$ may project a little way over the point of the lifting pallet *i n*, but not so close but that the point of the pallet may pass by the hooked end of the spring EF without touching it; the head of the adjusting screw *m* is also supposed to bear gently on the inner side of the said spring EF, or that nearest to the wheel, and at the same time the locking pallet is so placed that one of the teeth D, of the ballance-wheel, may just take hold of it. This pallet is not visible in its proper place in the figure, being covered from sight by the screw *m*, and part of the spring EF; its position is therefore represented by the dot *k*, on the opposite side of the wheel, having the tooth A just bearing up against it. From the above description of the several parts of the escapement, and their connexion with each other, it will be easy to see the mode of its action, which is as follows.

A force being supposed to be applied to the balance-wheel, so as to cause it to move round in the direction of the letters ABCD, one of the teeth, as D, will come up against the locking pallet (as represented at A, and the locking pallet by *k*). The wheel is then said to be locked, being prevented from moving forward by this pin. Let the balance be now supposed to rest in its quiescent position, and it will have the

situation represented in the figure; the lifting point *i*, of the pallet *in*, will be just clear of the projecting end of the slender spring, the face *h l* of the large pallet MSK will fall a little below the point of the tooth B, and the balance having its spiral or helical spring applied to it (which is here supposed on the other side of the plate PQRS, and of course not visible in the figure) remains perfectly at rest in this position. Now as the balance ULHV, and the two pallets MSK and *i n*, are fixed fast to the verge, it is plain they must all move together; let therefore the balance be carried a little way round in the direction of the letters VULH; by this motion the end *i* of the lifting pallet *i n* will be brought to press up against the projecting end of the slender spring, and as this spring is fixed on the side of the spring EF, nearest to the balance-wheel, the point *i* will press the two springs together out from the balance-wheel; then, as only the point of the tooth D (see its position at *k*) touches the locking pallet, when the spring EF was at rest against the head of the screw *m*, it will, by the spring being pressed out from the tooth, have slipt off (for the locking pallet which was before supposed at *k*, will now be at *a*, clear of the tooth A of the balance-wheel); the wheel being now at liberty will move round by the force supposed to be applied to it; but as the point *i* of the lifting pallet moves on and presses out the spring, the point *l* of the large pallet approaches towards the point of the tooth B of the balance-wheel, so that when the spring EF is sufficiently pushed out to unlock the wheel, the point *l* of the large pallet will be got to *d*, and in this position the point of the tooth B of the balance-wheel will fall upon it (see Fig. 2d,) where the tooth B is represented in contact with the pallet at *l*; at the same time the point of the tooth D has just dropt off from the locking pallet *m*; the force of the wheel being by this means applied to the top of the pallet *hl*, gives an increased momentum to the balance, and assists it in its motion in the same direction, and by the continued motion of the large pallet in the direction MSK the point of the tooth B, which keeps pressing and urging it forward, moves up towards the bottom of the face of the pallet towards *h*, until the

plain flat surfaces of the tooth and pallet come into contact (see Fig. 3d); by this time the end *o* of the slender spring has dropt off from the point *i* of the lifting pallet, and the two springs have returned again into their quiescent position, the spring EF gently bearing against the head of the adjusting screw *m*, and the locking pallet in a position to receive the next tooth C of the balance-wheel; (see the position of the point of the lifting pallet at *i*, Fig. 3d, also the locking pallet at *m*, and the approaching tooth at C.) When the two surfaces of the tooth and pallet are thus in contact, the greatest force of the wheel is exerted upon the pallet, and of course upon the balance moving with it. The tooth still pressing against the face of the pallet, and the pallet moving in the direction MSK, it at last drops off, (see Fig. 4th, where *m* represents the position of the locking pallet, C the position of the tooth of the wheel just before it drops upon it, and *l h* the position of the face of the large pallet, having the point of the tooth B, just ready to leave it at *l*,) leaving the balance at perfect liberty to move on in the same direction in which it was going. Just as the point of the tooth B, which has been pressing the large pallet round, is ready to leave it, the next tooth C of the wheel is almost in contact with the locking pallet *m* (see Fig. 4th) so that the instant the tooth B drops off, the wheel is again locked, and the action of that tooth upon the balance is finished. As the balance moves with the greatest freedom upon its pivots, the force of the tooth has given it a considerable velocity, so that the balance still keeps moving on in the same direction, after the pressure of the tooth is removed by slipping off from the pallet, until the force of the pendulum spring (which is not represented in the figure) being continually increased by being wound up, overcomes the momentum of the balance which, for an instant of time, is then stationary, but immediately returns by the action of the pendulum spring, which exerts a considerable force upon it in unwinding itself. As the balance returns, the point *i* of the lifting pallet *i n* passes by the ends of two springs EF *yo*, and, in passing

by, pushes the projecting end, *o*, of the slender spring in towards the balance-wheel, until it has passed it ; which, as soon as it has done, the projecting end *o* again returns and applies itself close to the hooked end of the spring EF, as before. The spring *yo* is made so slender, that it gives but little resistance to the balance, during the time the point *i* of the lifting pallet is passing it, and of course causes but little (if any) decrease in its momentum. During the time the point *i* of the lifting pallet is passing the small spring *yo*, the long spring EF remains steadily bearing against the head of the adjusting screw *m*, as the hooked end at *o* just lets the ends of the lifting pallet pass by without touching of it. As the spring has now been continually acting upon the balance, from the extremity of its vibration in the direction MSK, it has given it the greatest velocity, when the point *i* of the lifting pallet is passing the end *o* of the slender spring ; for at this instant the spring which was wound up by the contrary direction of the balance, is now unwound again, or in the same state as it was in its quiescent position at first, and of course has no effect upon the balance at all in either direction ; but the balance having now all the velocity it could acquire from the unwinding of the spring, goes on in the direction UVHL, until the force of this spring again stops it and brings it back again, moving in the same direction as at first, with a considerable velocity. By this return of the balance, the point *i* of the lifting pallet comes up again to the projecting end *o* of the slender spring, pushes back the long spring EF, and unlocks the wheel ;and another tooth falling upon the face of the pallet *hl* gives fresh energy to the balance ; and thus the action is carried on as before.

QUESTIONS

PROPOSED BY

THE BOARD OF LONGITUDE

TO

MR. EARNSHAW

RELATIVE TO

HIS SPECIFICATION OF HIS TIME-KEEPER,

WITH HIS ANSWERS TO THE SAME.

QUESTIONS, &c.

Quest. I. Page 1, line 10. Explain this?

Ans. I do not know any words in the English language that can explain this better than the words I have used in my Specification.

Quest. II. There are certain best sizes for the scape wheel detent and pallets in proportion to that of the balance. What are they?

Ans. The sizes for the scape wheel detent and pallets in proportion to that of the balance, are given in Plate I. fig. 1. where the exact size of balance may be seen; and in Plate II. fig. 1. are the sizes for scape wheel detent and pallets.

Quest. III. Page 1, second paragraph. Are you here describing a box or pocket Time-keeper? What should be the respective sizes of the pivots of the ballance axis for each?

Ans. The whole of my Specification is on Box Time-keepers for the determination of the longitude; I have nothing to do with inferior articles, which Pocket Watches are; but I have no objection whatever to give the fullest explanation on them. Therefore the size for pivots of balance axis for Box Time-keepers are, as I have before described them in my Specification, viz. about the size of the verge pivots of a good common sized Pocket Watch. The Pocket Time-keepers a very little smaller. No description can be given that the Trade are so well acquainted with as this.

Quest. IV. Page 2, line 22 to 29. Explain this?
Page 3, line 4. Explain this?

Ans. Line the fourth, to the end of paragraph cannot be better explained but by examining the model and shewing it in action, which I shall be very willing and ready to do, at all seasonable hours, to any person or persons, except some of the Watch-makers, who are my declared enemies.

Quest. V. Page 3, line 12. What is the diameter and weight of the ballance for a given main power, and likewise for a certain number of vibrations, viz. 18,000 in an hour, which is essential to determine, as it would serve as a general theory?

Ans. The diameter of balance is given in Plate I. fig. 1. in my Specification, in proportion to a given main power, in the same Plate fig. 3, and under it letter b. After any one has made it as described in this plate, let them put it into a scale, and the weight will appear. Then, if they look into the thirteenth page of my Specification, line 25, 26, and 27, they will find every thing relative to the train. Those persons or person who asked this question have either blinded themselves, or have not read my Specification. However, diameter of balance without the weights and screws is $1\frac{1}{8}$ inch, with them $1\frac{3}{8}$ inch. Weight of it with compensation weights and screws 3 dwt. 10 grains. Diameter of barrel which contains the main spring, or first maintaining power, 1 inch $\frac{1}{8}$ and $\frac{1}{16}$; height of it $\frac{1}{2}$ inch. The spring therein contained $4\frac{1}{2}$ or 5 turns, which is an unerring guide for any one.

Quest. VI. Page 3, line 17. What is the thickness of the steel rim of your balance in thousands of an inch? And what the size of the pivots of the ballance axis and of the pivots of the scape wheel?

Page 3, line 21. What is the weight of one of these screws?

Ans. The thickness of steel rim of balance is about $\frac{8}{1000}$ of inch, the size of ballance pivots the same, as near as I can measure; but the Watch-makers are better acquainted with the thickness I before described in my Specification, page 3, line 16, 17, and 18. The scape

wheel pivots should be the least matter larger than the balance pivots. The weight of one of the balance screws should be about five or six grains, a little more or less is not material.

Quest. VII. Page 3, line 24. What must be the size of the piece of brass from which the compensation weights are to be cut for Box and Pocket Time-keepers?

Ans. The size is given in Plate I. fig 1. where the compensation weights may be seen fixed on the balance, and those weights are separately shewn in Plate II. fig. 3 and 4, so that no one can be at a loss for them.

Quest. VIII. Page 4, line 8. Do you blue your balances? And if you do so, do you make any alteration to them afterwards?

Ans. I do blue the balances, but make no alteration afterwards.

Quest. IX. Page 4, line 25. As bending is condemned, what method do you use of restoring your balances to their circular figure after they have been cut open, as the circular figure is thereby lost, and the rims sometimes close and at others open?

Ans. I do not restore them to the figure they had before cut open, but blue them after cutting open, to preserve the natural figure they then take.

Quest. X. Page 7, line 5. What is the equivalent weight of one of the compensation weights?

Ans. About twenty grains, a little more or less is not material.

Quest. XI. Page 7, second paragraph. What internal defects occasion a watch to measure time differently in different positions? What position should the pallet of the balance have when at rest? And what is the effect produced by placing it in different positions?

Ans. Large balance pivots, because when the Time-keeper is in a horizontal position the pivot then acts on its point, but in a vertical

position they act on their sides, which is an increase of friction, the balance then cannot vibrate so far as when horizontal. Another cause of error in different positions is, when the Watch is in the position that the balance is under the scape wheel, its vibrations will be different to those when in the position which places the balance over it; and if the long and short vibrations are not performed in the same time, or nearly so, the Watch must vary in the different positions from that cause, and other causes too absurd for me to write on, as they are well known to the Trade. When the balance is at rest, the face of the pallet should stand exact to the point of wheel tooth, as in Plate II. fig. 1. Only observe, that the engraver has not placed the pallet near enough to the wheel, it should be as near as possible so it does not touch it. If you place the face of pallet without the tooth of wheel on right hand side, then, when the wheel is unlocked, it will fall on the round of pallet instead of the face of it, and cause a considerable rubbing; and if placed more within the tooth it will have too much drop, a term in Scapements which all Watch-makers are well acquainted with. This can be beter explained by the model in action, or by examining the drawing of it.

Quest. XII. Page 7, line 20. When the weight is wanted to adjust the Watch in the positions of 3 and 9, by what means do you obtain that weight, in the manner your balance appears to be made? If you know any thing more, that is material, concerning the making Time-keepers go nearly the same in different positions, communicate it?

Ans. To adjust the watch in the positions of 3 and 9, I fix on to one of the compensation weights that is downwards, when in that position that it loses most, a small piece of brass not larger in diameter than a common pin head; and nearly as thin as foolscap paper. I fix it on with a very small particle of bees wax, not larger than the common dot of an i; that is, if the Watch is gaining on mean time. But if the watch is losing, I then take out the balance, and, with a dril, dril out a small matter from that compensation weight that is uppermost when in the

position that the Watch loses most; this I have found to correct it, without so many screws and fans as I have seen in some Time-keepers.

Quest. XIII. Page 7, last paragraph. What is the length of the balance spring in your Box Time-keeper, and what in your Pocket Time-keeper?

Ans. About the usual length of Mr. Arnold's; various as his are, from 12 to 20 inches in Box Time-keepers, and in Pocket ones from 5 to 7 inches, just as I can get the wire to answer the purpose.

Quest. XIV. Are your balance springs made of soft steel, or tempered? And if tempered, in what manner?

Ans. My Balance springs are made of soft steel, rolled hard, and not hardened and tempered with heat and cold, that process not being at all necessary.

Quest. XV. How is the balance spring turned into its proper shape?

Ans. It is turned round a brass cylinder, and then blued by heat, which sets it into the cylindrical form.

Quest. XVI. Page 8, line 17. Explain what you mean by this? And how it is performed?

Ans. All Watch-makers know how to draw and taper balance springs, though they did not know how much they were to be tapered to that certain degree which could only answer the purpose of a complete Time-keeper. I perform it in the following manner: take a length of balance spring wire, say about 12 inches for Box Time-keepers, and draw it between two smooth potence files, beginning from the end about $\frac{1}{6}$ of its length, make one draw; the next about $\frac{2}{6}$; and so on, advancing $\frac{1}{6}$ every draw till you come to the top, pressing the files just so hard together as will make them bite or take

hold of the spring; do the same with two oil stones, only give twelve strokes instead of six, which will take off all burs which the file left on.

Quest. XVII. Page 8, line 5 from bottom. As you say that the balance spring will continually lose of its power by use, is there any method of restoring it to its original strength? And what?

Ans. By giving it rest.

Quest. XVIII. Page 9, line 7. Be pleased to explain clearly and fully the proper shape of the spring, and your manner of making it, to produce the effect here described?

Ans. This is fully explained in my answer to the 16th question.

Quest. XIX. Page 9, line 11. How is the Watch made to vibrate $\frac{1}{3}$ of a circle, or a circle and a quarter, or confined to a circle and a quarter?

Ans. Make the Time-keeper in all its parts as described in Plate I. and II. and it will produce this vibration $1\frac{1}{4}$ circle; if not so much, the balance must be lightened, or a stronger main spring put in, which ever is most convenient; but if it vibrates more, then, by turning the small pallet a little nearer to the face of large pallet, so as to give the scape wheel a little more drop, will shorten the vibrations; or setting the detent spring in a little stronger, will likewise shorten them.

Quest. XX. Page 9, line 9 from bottom. If a spring, after being applied to a Time-keeper, is found not to render it correct, can the same spring be altered to correct it? And if so, how performed?

Ans It may be altered, but I advise making another. Every beginner must expect to have some little loss at first, but in a short time, by habit and attention, they will be able to make them so near, that if they are not quite exact, they will be exact enough for Time-keepers of inferior prices, and the maker will be able to accommodate various purchasers who will not give the highest price.

Quest. XXI. Page 9, line 2 from bottom. Does altering the length of a balance spring, of uniform thickness throughout, alter the performance of a Watch in any other way, except that of making it gain or lose on mean time?

Ans. I never used the lengthening or shortening the spring for any other purpose but that of making the Watch gain or lose. Le Roy published many years back, that a certain length would produce isochronism; and Arnold says he has used it for that purpose. I use a method truly English, contrived by myself, and produce isochronism by tapering.

Quest. XXII. Page 10, second paragraph. Explain this?

Ans. My scape wheel is locked on the extremity of it, and unlocks in a similar circle which the wheel makes, which renders it a perfect dead scape. Arnold's is locked on the other side of the wheel, and in the act of unlocking the spring moves in towards the centre of the wheel, which is a different direction to that which the wheel takes, and produces recoil. If the Watchmakers cannot understand this, it is clear then that I have told them something. My scape wheel, being locked on the extreme point, is easier unlocked than Arnold's, which is locked nearer the centre. Mr. Peto acknowledged, in the presence of Mr. Frodsham, many years back, that the above two circumstances were a great cut upon Arnold, and in consequence proved my scape to be so superior to his.

Quest. XXIII. Page 12, line 5 from bottom. Explain this?
line 4 from bottom. Explain this?

Ans. This is fully explained in No. 22 above.

Quest. XXIV. Are the Time-keepers No 520 and No. 543, made by you for the Board of Longitude, complete specimens of your improved Time-keepers?

Ans. They are, as near as necessary.

Quest. XXV. Page 15. How are your three Plates to be understood, with respect to the sizes of the parts of your Box Time-keeper, and Pocket Time-keeper?

Ans. I before observed, that I had nothing to do with Pocket Time-keepers; but if any Watch-maker wants their sizes, they ought to know them from the Box ones, as set forth in my Specification; if they do not, they may see them in any of my Pocket Time-keepers, as I have turned out hundreds of them, and with which they are well acquainted; and if further explanation is wanted, it can be better given to them by exhibition, which I have before promised to give.

Quest. XXVI. Page 18, line 7. Is there any particular nicety in making the detent springs? How are they brought to their proper shape? hardened, tempered, &c.? What alteration will take place in the performance of the Watch, in consequence of any alteration in the stiffness of those springs?

Ans. As the detent spring is to fall into the teeth of scape wheel, to stop it at every tooth, it should be no stronger than just necessary to do so; and such strength can be obtained by any Watch-maker looking at one, and trying its strength with the finger; and indeed they can hardly make them too weak, so they do not cockle. They are brought to their proper shape by files, and afterwards smoothed with a piece of steel and oil-stone powder. I do harden and temper them. If the spring is stronger than necessary, it will produce friction and impede the motion of the balance; for, as the swing of the balance is to unlock the wheel by moving the spring out of it, it is 16 times more easy for the balance to move a spring of the force of one ounce to that of the force of one pound; therefore a detent spring too strong is a great evil, and they can hardly be made too weak, and it is perfectly easy in the making to find the right strength.

Quest. XXVII. Page 18, line 3 from bottom. How should the lifting and large pallet be placed with respect to each other? And how are

these pallets made and adjusted? As the unlocking of the wheel depends upon the relative situations of the lifting and large pallets, what alteration will take place in the performance of the Watch by varying the positions of those pallets?

Ans. The lifting and large pallets are twisted on the same round axis, and may be moved with ease into any circular direction to each other; and the small lifting pallet must be moved round to such position, that when the wheel is unlocked the face of large pallet should be just within the compass of the wheel tooth which is to act on it. The pallets are made of steel, and jewels set in them for the acting parts. The effect produced by not setting these two pallets right, is fully explained in the last part of my answer No. 11.

If these answers are not thought sufficient, I beg leave to say that I do not know how to explain them better, and no written explanation can be any way equal to an exhibition of the machines. And if many of these questions were started by Watch-makers, it is clear to me that they will not understand any thing I can write on this head.

EXPLANATION

OF

TIME-KEEPERS,

CONSTRUCTED

By Mr. ARNOLD.

DELIVERED TO THE BOARD OF LONGITUDE BY MR. ARNOLD,
MARCH 7th, 1805.

EXPLANATION, &c.

TO THE HONOURABLE

COMMISSIONERS OF LONGITUDE.

GENTLEMEN,

HAVING been honoured with your commands to give a description of the time-keeper invented by my Father, with the mode of adjustment now used by me, I shall endeavour, as clearly and as briefly as I am able, to give you every necessary information. I consider the chronometrical part of the time-keeper to be confined altogether to the balance spring, the balance, and the escapement. The other parts are no more than a good horizontal movement, which may be of any dimensions from two inches and a half in diameter, to five or more, and of proportionable depth, and may be constructed to go a day, a week, a month, or even a year (though the last may not be quite so well) at the option of the maker.

A large model is easier to be understood than a small one, and on that account plate 1 represents a lateral view of a time-keeper of large dimension, exhibiting *A* the upper plate. *B* the pillar plate. *CCC* pillars, on the heads of which, above the upper plate, are collets and screws, to fasten the upper plate to the pillars, the other ends of them being rivetted into the pillar plate *B*. *DDD* the potence. *EE* the cock. *F* the fusee. *G* the great wheel acting in the centre wheel pinion 3. *H* the detent arbor and detent, which falls into the per-

petual ratchet 2. The fusee is constructed in the usual way to keep the time-keeper going during the time of winding. *I* the centre wheel arbor, with the centre wheel pinion 3, parallel to the great wheel *G*, and below the pinion, and partly under the great wheel, is the centre wheel 4. *K* the third wheel arbor, with the third wheel pinion 5 below, in which the centre wheel 4 acts, and under the pinion (which cannot be seen because it is sunk into the pillar plate *B*,) is the third wheel. *L* the fourth wheel arbor, upon which, partly under the potence, is the fourth wheel 6, and below that, and partly sunk into the pillar plate, is the fourth wheel pinion 7, in which the third wheel acts. *M* the balance wheel or escapement wheel arbor, whereon is the balance wheel pinion 8, toward the pillar plate, and in which the fourth wheel 6 acts. At the other end of the same arbor, just under the upper plate, is the balance wheel, or escapement wheel 9. *N* the barrel bridge or cap, which is hollowed and raised above the upper plate, to increase the height of the barrel *W*, which is under it, and which contains the main spring. 10 The barrel arbor square, upon which is a ratchet 11 just over the barrel cap; and upon the barrel cap is a click, (which cannot be seen), and a click spring 12. The ratchet, click, and spring, are placed in this situation, for the convenience of letting down or winding up the main spring, by applying a key upon the square 10, for the purpose of decreasing or increasing its force, in order to try the long and short vibrations of the balance. *P* part of the fusee arbor, on which toward the top of the cock *E*, is a piece 13, like a cup, called the fusee guard, which, sliding upon 14, the square part of the arbor, falls over the wind-up hole, to keep out dirt. From *Q* to *Q* is the balance, more particularly described hereafter. R the balance spring. *n* The collet whereon the balance is screwed. *m* The balance stud, between the balance and the spring, into one end of which the spring is pinned fast. *S* the plate stud, or mouth piece, screwed upon the upper plate, which opens or shuts as a vice, by means of the screw *r*, and by which the balance spring may be lengthened or shortened at pleasure. *TT* the verge, the arbor, or

the axis of the balance, passing from that part of the potence *D*, which is above the center pinion 3, to the top of the cock *E*, above the collet *n*. On this arbor is the impelling pallet 15, in the same plane with the balance wheel 9, and in which the balance wheel acting occasions the balance to vibrate. The small or discharging pallet cannot be seen, nor can the escapement or unlocking springs, as they are hidden by the thickness of the upper plate *A*, but the locking pallet *a* may be observed between that plate and the escapement wheel 9. In this view the dial plate 16 is at bottom, and consequently the face of it cannot be seen, the time-keeper being turned upside down. It is, in the usual way, divided into hours, minutes, and seconds; the seconds hand being carried upon the fourth wheel pivot. The hands appear below the dial plate 16. Between the pillar plate and the dial, is the motion work, made in the usual way. The holes in which the axis of the balance moves, and those of the balance wheel, must necessarily be jewelled. The center, third, and fourth, wheel holes may also be jewelled. The time-keeper is contained in a mahogany or brass case with a glass over the dial plate, and suspended in gimbols as a compass at sea. Or if it is adjusted to go alike in all positions, it may be put into a box stuffed with horse-hair cushions.

Was Plate I. turned the other way, or the time-keeper in its proper position, which is horizontal, dial upwards, the balance would be at the bottom, below the balance spring, near the cock *E*; and was the end of the spring out of the plate stud *S*, the coils would all be close together as in Fig. 4, Plate II, and in contact with each other; the spring not appearing much more than half the height or depth which it does in plate I. The spring being extended by the weight of the balance (which does not wholly rest on the jewelled endpiece which is set in the cock); if the cock were to be taken away, the balance would remain suspended nearly in its present situation, and would drop very little lower than it now is. And as the spring is extended or drawn up, so will the weight of the balance be taken from off the cock, insomuch as even to bear considerably against the endpiece in the potence. In the

time-keeper, the balance is made to bear a little on the cock; by this means a considerable degree of friction is avoided, which must take place if the whole weight of the balance rested entirely on the end-piece without relief.

The method of suspending the balance by the spring, is not followed in pocket chronometers. For in them, there is no barrel cap *N*, and the Balance runs close above the upper plate *A* on the middle of its axis, the balance spring being between it and the cock; the cock being not so much as half of the present proportional height.

Plate II. 18 represents the tops of the pillars, with the pillar screws. *N* the barrel cap: 19 the two screws which fasten it to the upper plate *A*: 11 the ratchet, 21 the click, 12 the click spring, 14 the fusee square, 13 the fusee guard. *G* a portion of the great wheel which appears from under the plate. *B* the pillar plate projecting a little beyond the upper plate *A*: 16 the back of the dial plate. III. VI. IX. and XII. the four hours, three, six, nine, and twelve, (as the time-keeper is now placed face downward,) as a guide to explain the adjustment for positions: 23 one of the screws which fasten the jewelled hole partly under the plate stud S, in which the pivot of the fourth wheel runs: 22 the jewelled hole, in which the pivot of the escapement wheel runs, fastened by two screws: 9 the balance wheel, which runs under the plate *A*; some of its teeth may be seen in the notch through the plate, the plain circle above only serving to shew its situation below the plate. *E E* the cock, supposed transparent, to shew the balance, the balance spring *R*, and the balance stud *m*, which crossing the center of the balance, is marked by dots. The escapement spring, which is hidden in Plate I, may be here distinguished. Let *a* represent the end of the escapement spring screwed upon the upper plate *A*. From this end a notch is cut through the plate, which continues round the axis of the balance, and includes the impelling pallat 15:—17 is a rectangular hole, or notch, cut through the upper plate to admit the head of the adjusting screw, the tap of which going through the solid part, between the two notches,

touches the back of the locking pallet. What relates to the escapement will be treated of hereafter, I shall next proceed to describe the balance spring and balance, the drawings of which correspond in size with the time-keeper.

Of the Balance Spring, with the mode of rendering it Isochronal, or of adjusting the long and short Arcs of Vibration of the Balance. The Term long Arcs and short Arcs, large Arcs and small Arcs, are used indifferently.

The balance spring may be made of steel wire hardened and tempered, of steel wire hard rolled, or of gold wire alloyed with copper. Steel wire hardened and tempered is the most elastic—then gold, and, lastly, steel wire hard drawn. Springs composed of either of the above substances, if the materials be good, will answer the purpose. The quantity of copper alloy put to the gold, has been found to answer in the proportion of from one eighth to a quarter, and many other proportions may probably do as well. The form of the spring is helical, or cylindrical, except for a portion of the turn at each end, where it is curved in, and fastened at an equal distance between its center and circumference, which may be seen by inspecting one end at the stud *m*, and the other at the stud *S*, Plate II, Fig. 1, and 3. It may also be observed in Plate I, that the two end turns are curved in or smaller than the others. Were not those turns to be curved inwards, but left of the same diameter with the others, the spring would not have its present easy, concentric motion, but, on the contrary, would jolt, wabble, and be distorted. Whether the balance vibrates an arc of 230 degrees from its point of rest in its forward direction, and re-vibrates 230 degrees in its backward direction, making together 460 degrees, the cylindrical figure of the spring is still preserved.

Upon the length of this spring depends the isochronism of the vibrations of the balance; and in every spring of a sufficient length, there

is a place where all the vibrations, long, short, and intermediate, will be performed in equal times.

When the time-keeper is first set going, and always immediately after cleaning and putting into good order, the main spring pulling with all its force, the oil applied to the pivots clean and good, and every part performing its functions to the greatest advantage, the balance may vibrate from 180 to 230 degrees from the point of rest, according to the power of the main spring, and the relative weight of the balance. The balance also re-vibrates on the other side of the point of rest nearly the same arc, but here the vibration is only reckoned on one side.

From continual exertion, the main spring will undergo some diminution of its original power, and very great resistance will be created from the thickening of the oil, and from the accumulation of dirt, so that at the end of a long voyage, suppose three or four years, the arc of vibration of the balance will gradually decrease from 230 to probably 130 degrees, and so on, till in time it will come to rest. From which it must be evident that if the different arcs from 230 to 130 are not all performed in equal times, a great irregularity must from that cause take place. If the large arcs are performed in longer time than the small ones, the time-keeper will accelerate, or go faster and faster; and if the small arcs are performed in longer time than the large ones, it will retard, or go slower and slower. To adjust the long and shor arcs, let the time-keeper when clean, and the balance vibrating to its greatest extent, go for a few hours, and then without stopping it, by means of the click and ratchet above the barrel cap, and a key applied to 10 the barrel arbor square, let the main spring down a turn or two, till the arc of vibration decreases from 230 to 130 degrees or thereabout. Then let it go for the same time as before, and if it goes slower with the long arcs than with the short ones, which is generally the case, shorten the spring, by drawing it through the lips of the stud *S*. Then try it again in the same manner, and so on, till they are performed in equal times.

If on the contrary the short arcs should be performed in longer time than the long ones, or the long arcs be performed in less time than the short ones, which amounts to the same thing, the spring must be let out, or lengthened at the stud *S*, and so on repeatedly, until they correspond. If after letting out the spring several times, there should be no more to spare, a longer spring must be made. The length of spring in the time-keeper before us is about 18 inches.

If the spring is made of hard rolled wire, and the construction should be such as not to leave room for a spring of the usual length, and one much shorter than ordinary should be required, it will be very liable to be overstrained, if of rolled wire, and if hardened and tempered, or of gold, to break. It will however be a good deal relieved and assisted by tapering, the tapered end being pinned into the balance stud *m*.

Of the Balance, and the Mode of making it to keep the same Time in different Degrees of Temperature, or of adjusting it for the Effects of Heat and Cold.

The cock *E*, see Plate II, Fig. 1. supposed to be transparent, that it may not prevent the balance from being seen. Let *b b* represent the arms of the balance, which are broken off toward the centre, to give a view of the spring, the pallets, &c. The balance is screwed upon a collet *n*, fixed on the end of the axis (see Plate I.) At the extremities of these arms are two shoulders *cc*, against which, by two screws, are fixed the expansion or compensation pieces *ddd*. These expansion pieces are composed each of two laminæ, the outside being of brass, the inside of steel. These two pieces are made out of one, the brass being melted upon the steel all in one piece. It is afterward cut into two. *de* the steel laminæ continued, but made round, and tapped. *gg* brass balls, or weights, alike in all respects, made to screw

upon each tap. In the sides of these balls are two holes between the centre and circumference, made to receive a tool like a two-pronged fork, called a fork screwdriver, to screw the balls higher or lower. *ff* two side screws to assist in making the balance of an equal weight. *hh* screws to regulate the mean time, and which are tapped into the shoulders *cc*, passing through the expansion pieces. The long and short vibrations being adjusted, I shall next shew how to make the time-keeper perform alike in heat and cold. The balance spring becomes weaker by heat, and stronger by cold, and was the balance to remain of the same diameter, it would go slower in heat, and faster in cold, supposing it to go to time when the thermometer stood at temperate. But when the spring becomes weaker by heat, the expansion pieces move *toward* the centre of the balance, carrying with them the balls *gg*, by which the diameter of the balance becomes smaller, and relatively lighter. When the balance spring becomes stronger by cold, the expansion pieces move *from* the centre of the balance, carrying with them the balls *gg*, by which the diameter of the balance becomes larger, and relatively heavier; and when, after repeated trials, the balls are properly placed, at equal distances on each tap, the diameter of the balance will decrease and increase, in the same ratio as the spring decreases and increases in strength. The following is the cause of the expansion pieces moving toward the centre by heat, and from the centre by cold. As the outside lamina of the expansion pieces is of brass, and expands, or lengthens, more by heat than the inside lamina of steel, to which it is attached; it will be easy to conceive how the brass forces the steel inwards; and as the same lamina of brass contracts or shortens more by cold than the steel, it is obvious that it must draw it outwards. (Was the lamina of brass placed inside, and the steel outside, the balance would expand, or become larger by heat, and contract or become smaller by cold, and instead of compensating the error of the spring, it would add to it.)

The balls *gg*, being made of equal weight, may be placed at the end of the taps at *e*; and if the time-keeper, being in a situation where the thermometer will rise to 100 degrees or more, should go faster than when placed in another situation where the thermometer will fall to 32 degrees or lower, it is a proof that the expansion pieces do too much, and that the balls are too heavy. Supposing this to be the case, screw the balls up close to the ends of the expansion pieces at *d*, and their effect will be less; because, notwithstanding the same degree of heat will occasion the expansion pieces to move inwards, the same quantity, or to describe the same angle from *c*, yet the balls will move through less space at *d* than at *e*. For it is evident, that if they could slide up to the ends of the expansion pieces, next to the arms of the balance, they would not move at all, or at least, their motion could not be discovered by any effect that it would produce. If the time-keeper still gains in heat, reduce the balls, and screw them up again to *d*. In the next trial, should it lose in heat more than in cold, contrary to what it did before, it is a proof that the expansion pieces do not do enough, and the balls must be unscrewed toward the ends of the taps at *e*, until it keeps the same time in heat as in cold. If the balls being at the ends do not do enough, and the time-keeper still loses in heat, increase their size until the adjustment is brought within the compass of the length of the taps, where there is generally room sufficient to correct for a minute of difference in heat and cold per day. By screwing the balls up and down, it may be soon seen how much of error two or three turns will correct in a given time, and by that means discover their proper situation.

Of Positions, or the Mode of adjusting the Time-keeper to go alike, or nearly so, in different Positions.

The long and short vibrations being adjusted, and also the heat and cold, I shall next shew how to adjust the different positions. Let us suppose that the two mean time screws *hh*, see Plate II, Fig. 1,

when the balance is at rest, stand at those points, where the hours 12 and 6 are marked upon the dial plate, and that the two side screws *ff*, stand at those points where the hours 9 and 3 are marked. If the time-keeper should go faster with the hour 12 highest (or vertical) than with the hour 6 highest, screw in the screw *h* a little at the hour 6, and unscrew the opposite screw at the hour 12, the same quantity, if it should lose most in that position, do just the contrary. The same rule is to be observed with respect to the hours 9 and 3, by the two side screws *ff*. It may however happen that the balance will not preponderate at either of these four points, or that the screws may not be sufficiently powerful to effect the purpose. In this case for the positions 12 and 6, by unscrewing a little one of the balls *gg*, and screwing in the other, we may succeed; but this method should not be practised in superior time-keepers, because by so doing, it will occasion one expansion piece to act more than it ought to do, and the other less, and destroy that equality of expansion, of weight, and of distance, which the very word *Balance* informs us ought to be preserved. To remedy this inconvenience, another method has been contrived, by which the balance may be rendered of equal weight, while the balls, the screws, and every opposite part, are at equal distances from the center. Let the balance be made with a light ring *xxx* (as in Figure 2, Plate II,) within the expansion pieces. Let there be three light equal weights *kkk*, which by a screw in each may be fixed upon any part of the ring; then having adjusted the long and short vibrations, and the heat and cold, and having the mean time screws at equal distances from the center, and the balls at equal distances upon the taps (there will be no occasion for side screws), try the time-keeper in different positions, and in a very few trials, by moving the weights upon different parts of the ring, the positions may be adjusted very accurately. The weights may be brought all to the same part, and the balance made to preponderate in any given point, and none of the other adjustments will be affected by it, and the weights, upon whatever parts of the circle they

may be, will still remain at an equal distance from the center. Having adjusted for long and short vibrations, heat and cold, and positions, it remains only to regulate for mean time. Should the time-keeper gain, increase the diameter of the balance by drawing out an equal quantity of the two mean time screws *hh*, and should it lose, decrease the diameter, by screwing in an equal quantity of the same screws. This adjustment does not affect that for heat and cold, because these screws are unconnected with the expansion pieces, nor will they affect the positions, if they are both turned the same quantity, and the taps of the same thread.

OF THE ESCAPEMENT.

In Plates I, and II, is very distinctly seen the relative position of the escapement to the other parts of the time-keeper. In those plates the balance and spring are upon a scale sufficiently large to be understood, without much difficulty, but the action of the escapement may not be so easily comprehended as by a drawing upon a large scale.

Fig. 1, Plate III, represents the escapement wheel, the teeth of which are of a cycloidal shape, and whose upper surface towards the extremity presents to the view a triangular form, two sides of which are described by right lines, and the other by a cycloidal curve, which is the principal part of action; (a few of these teeth appear through the notch in the upper plate *A*. Plate II;) but the triangular part of the tooth is not so plain as in Plate III.

In this plan the whole of the escapement wheel may be seen, and its situation on the arbor *M* in Plate I may be referred to. *BBd* the escapement or locking spring, screwed fast by its end *C* to the pillar *D*, and extending from *C* to *d* in the direction *CBN Bd*. (In Plate II, Fig. 1, the end *a* of this spring is screwed upon the upper plate *A*, and the spring itself, with the locking piece, sinks into the notch cut through the plate. Upon taking a side view of the upper plate *A* in Plate I, its thickness may be observed. Through this plate the locking pallet meets the escapement wheel 9.) The center of motion of this spring is between *C* and *N*, the part *NBd* being more substantial than the part *CBN*, and into which part between *N* and *B* is fixed the locking piece *a*; this locking piece, or locking pallet, whose acting surface is a jewel (see also Fig. 5, Plate II.) placed between *N* and *B* opposite the end of an adjusting screw *F*, and below the escapement spring, locks upon the interior angle of the tooth 2, and

upon every tooth in succession, suspending the motion of the escapement wheel for a time, and leaving the balance to vibrate without interruption from any part of the machinery. It is to be observed, that the triangular parts of the teeth of the wheel *AAA*, the wheel being hollowed or sunk, are raised above the periphery of the wheel to meet the locking piece *a*, so that upon viewing the wheel edgewise, see Fig. 5, (and also 9, Plate I,) the teeth will appear broader than the edge of the periphery *b*. In Fig. I, the locking pallet *a* being in contact with the tooth 2, is not so well distinguished as in Figures 2, 3, and 4, where it appears very plainly over the periphery *b* of the wheel, in the interval between the teeth 1 and 2.

(Fig. 5, Plate II, gives a view of the escapement spring reversed, and Fig. 6 explains upon a large scale the figure of the locking piece, which is angular, adjoining that part of the straight edge where the locking is effected. Was this angular part to be left square, like the opposite end, it might strike against the interior angle of the tooth, as the escapement spring returns to its place against the adjusting screw, after having unlocked or discharged the wheel, but by being of this figure it clears itself.)

Ne the discharging or unlocking spring, which is attached to the escapement or locking spring at *N*, and passes under the adjusting screw *F*, a little beyond the end *d* of the locking spring. This discharging spring is made very slight and delicate.

F the adjusting screw supported by the pillar *g*, (and which in Fig. 1, Plate II, passes through the solid part of the upper plate from the rectangular notch 17,) whose end is opposite to the locking piece or pallet *a*, on the contrary side of the escapement or locking spring, and by which the locking piece or pallet *a*, may be more or less advanced upon any tooth of the wheel; the escapement spring *BBd* always pressing the locking pallet *a* against the end of the screw *F*, except at the time of unlocking the wheel.

o, The unlocking, discharging or small pallet, whose part of action is a jewel. (The pallet with its jewel may also be seen above the im-

pelling pallet there marked 15 Plate II, Fig. 1.) When the balance is in motion, this pallet presses against the end of the discharging spring at *e*, and passing on in a direction from *e* to *d*, carries with it, for a short space, the discharging spring *Ne*, and also the locking spring *BBd*, moving them both at the same time, and in so doing carries the locking piece *a*, from off the interior angle of the tooth 2, (or any other tooth which may come into that situation) and leaves the wheel at liberty to impart its power to the impelling pallet. But when the balance returns, and the unlocking pallet *o* repasses the discharging spring *Ne* in a direction from *d* to *e*, it does not in the least disturb the locking spring *BBd*, nor consequently the locking piece or pallet *a*, but moves only, and for a short space, the unlocking spring *Ne*. *HHH* the impelling or large pallet whose part of action is at the angle *m*, where a jewel is placed. (This pallet and jewel may be seen in Plate II, Fig. I, where it is marked 15.) Upon the exterior of this angle the pallet receives its impulse from the cycloidal part of the tooth of the escapement wheel. The circumference of the pallet is incomplete from a portion being cut away to make room for the action of the teeth of the wheel.

X. is a circular hole under the periphery *b* of the escapement wheel, over the center of which the tooth 2 appears, and the locking piece or pallet *a*. The two springs *BBd* and *Ne* pass over it. This hole is made through the brass plate *QQQQ*, through which by inverting the escapement, the manner in which the locking piece *a* holds the tooth 2 (or any other tooth in succession) of the escapement wheel may be seen. (This may be understood from Fig. 5 and 6, Plate II.)

The impelling pallet *HHH* is supposed to be vibrating freely from *r* to *S*; here it is perfectly detached, or at liberty from the escapement wheel; as will be seen by observing that the unlocking pallet *o* is not in contact with the discharging spring *Ne*, nor are either of the teeth 3 or 4 of the wheel in contact with the impelling pallet. The balance or the impelling pallet (for they are both upon the same axis as in Plates I. and II.) vibrating from *r* to *S* the discharging pallet *o*

comes in contact with the discharging spring *Ne*, see Fig. 2, (and from that instant it is not detached or free, but in the act of escaping) and moving it in the direction from *e* to *d*, takes the locking pallet *a* from off the interior angle of the tooth 2, and sets the escapement wheel at liberty for the tooth 3 to act upon the angle *m* of the impelling pallet. Here the tooth 2 will be seen to have passed the locking piece *a*, and the tooth 1 to approach it. The tooth 3 pressing the impelling pallet from *r* to *S*, and continuing to do so as in Fig. 3, where the center of the escapement wheel, the angle *m*, of the impelling pallet, and the center *G* of both pallets form a straight line. This action of the wheel upon the pallet continuing as in Fig. 4, where the point of the tooth 3 is about to quit the angle *m* of the impelling pallet, the tooth 2 approaching nearer to the circumference of the same pallet, and the tooth 1 advancing toward the locking piece or pallet *a*, against which it falls, and is held fast, as soon as the end of the tooth 3 quits the impelling pallet. Here the act of escaping ends, and the impelling pallet is again detached or unconnected with the wheel, and moves in free vibration as in Fig. 1, for a certain number of degrees, until it is returned by the power of the balance spring and repasses from *S* to *r*, still independent of the escapement wheel or of any thing else, except the very little resistance which is encountered by the discharging pallet *o*, in repassing the discharging spring *Ne*, which it does without disturbing the locking piece *a*, or consequently the escapement wheel, and continuing for a certain number of degrees, is again returned by the balance spring from *r* to *S*, when resuming its situation, it is prepared to act as before.

It may be proper to remark that the action of the cycloidal tooth upon the impelling pallet is always the same, in the beginning as in Fig. 2, in the middle as in Fig. 3, and at the end as in Fig. 4, impelling the pallet with the same quantity of surface in action at all times, and at all times equi-distant from the axis of the pallet. This however depends upon the tooth having the true figure. From the foregoing description of the escapement, referring occasionally to the Plates I,

II, and III, the nature of the action of its different parts, and their arrangement in the timekeeper may be understood.

The proper shape of the cycloid is found in the following manner. Having a plate of smooth metal, fix upon it a piece of brass the size of the intended escapement wheel, which call the false wheel. Then take another piece of brass, the size of the intended pallet, which call the false pallet. On the circumference of the false pallet fix a fine steel point, and then rolling the false pallet upon the circumference of the false wheel, the steel point will describe a line on the plate, which will be the proper curve, in which shape the tooth must be cut by an engine. The larger the pallet in proportion to the escapement wheel, the less sudden the cycloidal curve will be, and the smaller the pallet the more sudden; so that an escapement wheel which has 15 teeth, with a pallet of a proportionable diameter, will have its teeth of a very different shape to those in a wheel which has only 12 teeth, because, in one case, the pallet is half the size, and in the other it is little more than one third.

The size of the pallet depends upon the number of teeth in the escapement wheel. The radius of the pallet should be equal to the distance between any two teeth of the wheel, and then their relative motion will be equal. If the wheel has twelve teeth, the radius of the pallet will be thirty degrees, measured on the circumference of the wheel, and its diameter sixty degrees, measured in the same manner, which will make it half the size of the wheel. If it has thirteen teeth the pallet will in diameter measure fifty-five degrees and a half. If fourteen teeth, fifty-one degrees and a half, and if fifteen teeth, which is the number generally applied to pocket Time-keepers, it will be forty-eight degrees.

The Marine Time-keeper, which has just been described, is made to beat half seconds, the balance making 240 vibrations both ways in a minute. For if the balance wheel has 15 teeth, the fourth wheel 80 teeth, and the balance pinion 10 teeth, there will be 120 beats, or half seconds, in one minute.

It is also made with the escapement wheel of 12 teeth, the balance

pinion having 7, and the fourth wheel 70; consequently there will be 120 beats, or half seconds, in one minute, as before. It has been already remarked that the pallet for 12 teeth must be half the diameter of the wheel, and for 15 teeth five twelfths, or fifty degrees.

The pocket Time-keepers, that they may not be disturbed by motion, have what is called a quicker train, the seconds hand making 150 beats upon the dial, or 5 beats in two seconds. The escapement wheel has 15 teeth, the balance pinion 8 teeth, and the fourth wheel 80, consequently there will be 150 beats in one minute, the pallet being 50 degrees in diameter, measured upon the diameter of the balance wheel.

No mention has been made of the numbers of the teeth in the other wheels and pinions, as they are of little or no importance, and may be varied considerably.

Should the foregoing description be found defective, or insufficient, I can only say that I shall be ready and willing to make what alterations and additions may be thought proper. Permit me, Gentlemen, to say how much I feel myself,

Your obliged and obedient Servant,

LONDON,
March 5, 1805.

JOHN R. ARNOLD.

QUESTIONS

PROPOSED BY

THE BOARD OF LONGITUDE

TO

MR. ARNOLD,

RELATIVE TO

HIS SPECIFICATION OF HIS FATHER'S TIME-KEEPER,

WITH HIS ANSWERS TO THE SAME.

QUESTIONS, &c.

Quest. I. Page 41, line 9. Are all these three substances equally good, and applicable in all cases to Box and Pocket Time-keepers? Or under what circumstances are they to be separately applied? And what advantage arises from applying one in preference to either of the others? Does not flatting or rolling pendulum wire destroy its elasticity, by crossing the grain of the wire so rolled? If so, do you use any means of making the grain of the wire longitudinal? if you do, it is required to explain the method.

Ans. All these three substances may be equally applicable in all cases to Box and Pocket Time-keepers. Springs made of gold and of tempered steel are attended with more trouble in manufacturing than those of hard rolled wire, and unless the gold is well compounded, and drawn or rolled perfectly sound, it is liable to break. In springs of tempered steel, the greatest care should be taken that they are in the first place hardened from end to end, and then they may be equally tempered throughout. They will be more elastic than gold, and perhaps better, excepting their liability to rust. Springs of hard rolled wire are the least elastic of the three, and are subject to lose of their elasticity, if made so short as either of the other may be. On this account, I leave them about a fourth part longer than the others, and if the material be good they will stand. They are made in less time, and with less trouble, than either of the others, but liable to rust. I do not know that flatting or rolling the wire destroys or impairs its elasticity, nor do I use any means to make the grain of the wire longitudinal.

Quest. II. Page 41, line 16. How are the above-mentioned balance

springs made; that is, how are they brought to, and known to be of a proper size, for each different watch; how turned into their proper shape, hardened, tempered, &c.? Is it necessary to attend particularly to the evenness of the wire? And if so, how is it known to be of an uniform thickness throughout?

Ans. I do not *(from experience)* pretend to know the exact proportional size of balance springs. I have made Chronometers with springs of the same length and material, some of them making or containing six or seven turns, others nine, ten, and even twelve, consequently differing considerably in size, and yet performing equally well. I should imagine that the best size would be such as that the spring might impel the balance in the centre of percussion, which will be between the centre and circumference of the balance, according as the weight may be disposed.—The springs of hard rolled wire are turned into their proper shape by winding them on a cylinder or mould, and screwing each end fast. The cylinder being heated by a blow-pipe until the wire becomes blue, it is taken off, and the ends turned in by a pair of bending pliers, or by drawing them over a round broach. Gold springs are brought to their shape by the same process, only that the mould, which may be of steel, is made blue instead of the wire. Or if the mould is of brass, the screws which fasten the wire may be of steel, and when they become blue, it will be the same thing as if the mould was of steel.

Springs are hardened by being made red hot upon the cylinder, either by a blow-pipe, or small charcoal fire, and then immersed in water or oil, and tempered by heating the cylinder with a blow-pipe until the wire becomes blue. There is a very great difference in steel: some sorts will be harder and more elastic at a blue than others at a yellow, and some again will bear letting down below a blue. It also happens sometimes that the very same piece of steel is of a better quality in one part than in another. The ends may be turned in by a pair of bending pliers made hot, or the mould may

be cut down or spiralled at one end for the first turn of the spring, and it will come off with that end ready turned in. The balance stud, into which that end is fixed, may be made moveable, or to shift, that is, to lengthen or shorten, so as to meet the curve of the spring, and then fastened by two screws. The other end turn of the spring, might also be fashioned in the same way, but as it may require to be shortened to find the isochronial place, the curve will be continually altering, and must be replaced by the pliars, so that it will probably be useless to do it by the mould.

I think it necessary that the wire should be as even as possible. I do not suppose that any wire was ever of an uniform thickness, but its deviation from uniformity may be known by drawing it through a parallel gauge. The best way I know of to make it as uniform as possible, is to grind it between two planes of hard steel with oil stone dust.

The Chronometer No. 36, which was tried by the Astronomer Royal five and twenty years since, had, and still has, the same spring of tempered steel. Mr. Everard's Chronometer, No. 68, had, and still has, the same spring of gold. And the Marine Chronometer, No 82, had, and I believe still has, a spring of hard rolled steel. Experience is in favour of all three. The length of the spring of No. 36 Pocket Chronometer was about eight inches. No. 68, about the same. No. 82, Marine Chronometer, sixteen inches, and of equal thickness from end to end. I think the gold and tempered steel will retain its identity longer than the other.

Quest. III. Page 41, line 2, from bottom. What is the necessary length of a spring, which shall contain that certain place? And how do you select that place or part from the whole?

Ans. That certain place is contained many times between the length of five inches and twenty, of and between which lengths, vast numbers of springs have been made. Those places are selected from

the whole, by continually shortening, as fully described in the method of adjusting the long and short vibrations.

Quest. IV. Page 43, line 9. As you do not recommend tapering the spring but in the case of there not being room enough for a spring of a sufficient length, is it necessary to have the balance spring of equal breadth and thickness; or, in other words, of equal strength in every part? If that is the case, what means do you use to make it so, since scarce any two following inches of the same wire, as it comes from the hands of the wire drawer, are of the same strength, and that a spring made of it, without preparation, would be compounded of various powers?

Ans. I only recommend tapering for hard rolled wire, but where there is perfect, or great elasticity, there is no occasion for it. The best hard rolled wire will not require it, unless made very short and overstrained, as may be the case in flat and fashionable Chronometers, where there is not sufficient room. The tapering is chiefly wanted at the bottom turn next the balance stud, which, from its spiral shape, is strained more than the cylindrical turns.

Wire, drawn through the plates where the holes are gradually smaller, will be of more equal thickness than rolled wire, unless the mill is excellent, as for that purpose it ought to be. The wire should be equal as possible, but none is perfect, and all springs are, and will be compounded of various powers, so long as we remain short of perfection. We can only come near it.

Quest. V. Page 43, paragraph fourth. Is there any difference in the action of the expansion pieces, when constructed of brass and steel of different qualities? And if so, what qualities are best, and how chosen?

Ans. I make use of good flat steel, and good Dutch brass, and having found it to answer, never tried any other.

Quest. VI. How are the expansion pieces turned into their proper and regular form? And how is the brass made to unite properly to the steel?

Ans. The expansion pieces are turned into their proper shape by a pair of hollow-mouthed pliers, and then heated to make them retain that form; and the brass unites to the steel by heat, without any solder ever having to my knowledge, been made use of; at least, during the last three and twenty years.

Quest. VII. What should be the relative thickness of the brass to the steel? And how obtained?

Ans. I make the brass twice the thickness of the steel, which thickness enables the brass to bend the steel easily, and I obtain it by measuring as near as I can.

Quest. VIII. Will any difference arise in the final performance of the watch, if the steel is hard, soft, or tempered? or from being hardened, or left in its natural state?

Ans. I cannot speak as to the difference, because I have always left the steel soft.

Quest. IX. Page 45, line 3 from bottom. Why does a machine measure time differently in different positions? Is it a defect arising from the imperfect execution of the escapement or other parts of the machine? And if not, what other cause generates this sort of error?

Ans. Theoretically, from the unequal weight of the balance only, and if the escapement was void of friction, it would be practically so. With a good and well made escapement the inequality lies almost altogether in the balance.

Quest. X. Page 45, paragraph 3. How are the detent springs made, and tempered, and placed in their proper positions? And what particulars are necessary to be observed in the making and placing them?

Ans. The detent springs are filed nearly to their proper substance, then hardened and tempered to a blue, sometimes not so low,

according as the nature of the steel may be, and afterwards ground to their proper strength. The locking spring is then drawn nearer to, or farther from the verge, so as to make the locking pallet hold each tooth of the wheel at an equal distance from the impulse pallet, after which it is steady pinned, so as it always may, if taken out, be returned to its place without further trouble. The unlocking spring is only to be in contact with the locking spring at the part where it is pinned fast, and at the end of the locking spring.

The spring should lock the wheel as light as possible, to do its duty, and the unlocking pallet should raise the unlocking spring as little as possible, to do its duty. The spring should point to the centre of the verge, and lift equally forward and backward. The end of the unlocking spring should be left rather stouter than the other part of it, to resist wearing.

Quest. XI. How are the lifting, locking, and main pallets made, and applied to their proper places? And what particulars are necessary to be observed in placing them, and how obtained?

Ans. The lifting, locking, and main pallets, are of steel hardened and tempered, with dovetails cut for the admission of jewels, of which their acting parts are composed.. (*See the Description of the Escapement.*) The situation of the lifting and main pallets to each other is such, as that when the wheel is unlocked, it may fall upon the main pallet before it comes to the line of centres, and to have as little drop as may be without butting.

Quest. XII. Page 52, line 7 from bottom. Does the cycloidal tooth always act upon the outermost edge of the pallet, as it appears to do in the three figures representing its action on that pallet?

Ans. The cycloidal tooth does act upon the edge as it appears to do.

Quest. XIII. Page 53, line 6 from bottom. Are the Time-keepers No. 82 and No. 176, made by your father for the Board of Longitude, complete specimens of his improved Time-keepers?

Ans. No. 82 and No. 176. are not perfect specimens, they have been made about five and twenty years.

I have endeavoured to answer, in the best manner I am able, the different questions which have been put to me, though, from the nature of some of them, I cannot give such direct and unequivocal answers as might possibly be expected. Concerning the question, contained under the first head, wherein it is required to state the advantage that might arise from applying one substance in preference to either of the others? As it is a doubtful matter with me, I cannot reply immediately to the point.

I have been rather particular upon the different springs, because upon their excellence the spirit of good performance chiefly depends. And I trust, I have explained as much concerning other matters, as will be sufficient to guide those, who have already a loose general knowledge of the subject. To others, who know nothing of the business, it will, I conceive, be useless to give any thing less than practical information.

T. Bensley, Printer,
Bolt Court, Fleet Street, London.

Fig. 1.

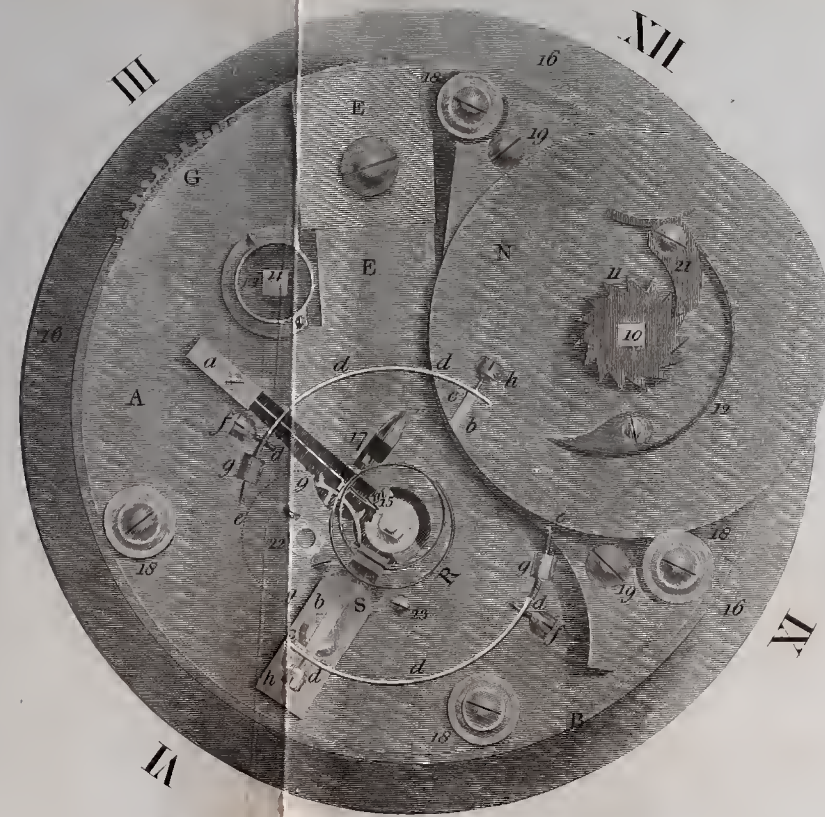

Fig. 2.

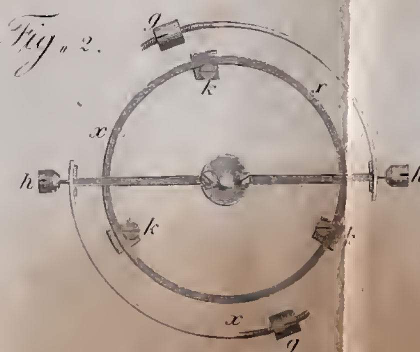

Fig. 3.

Fig. 4.

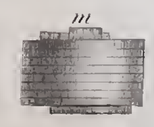

Fig. 5.

Fig. 6.

Blunt del.

J. Basire sc.

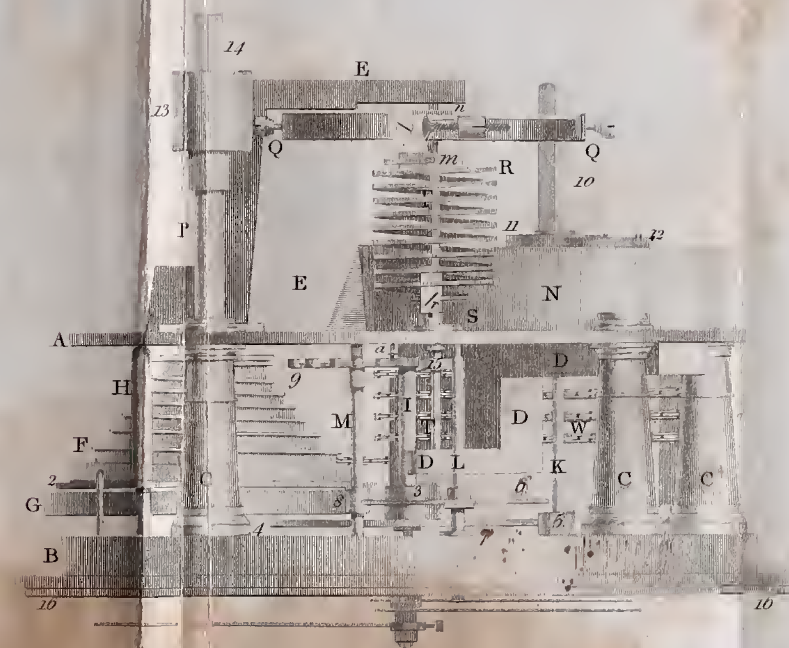

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Fig. 1.

Fig. 2.

Fig. 3.

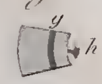


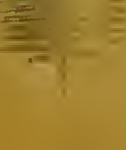
Fig. 4.

Fig. 5.

Fig. 1.

Fig. 3.

Fig. 5.



From the Model of Mr. Earnshaw's Escapement.

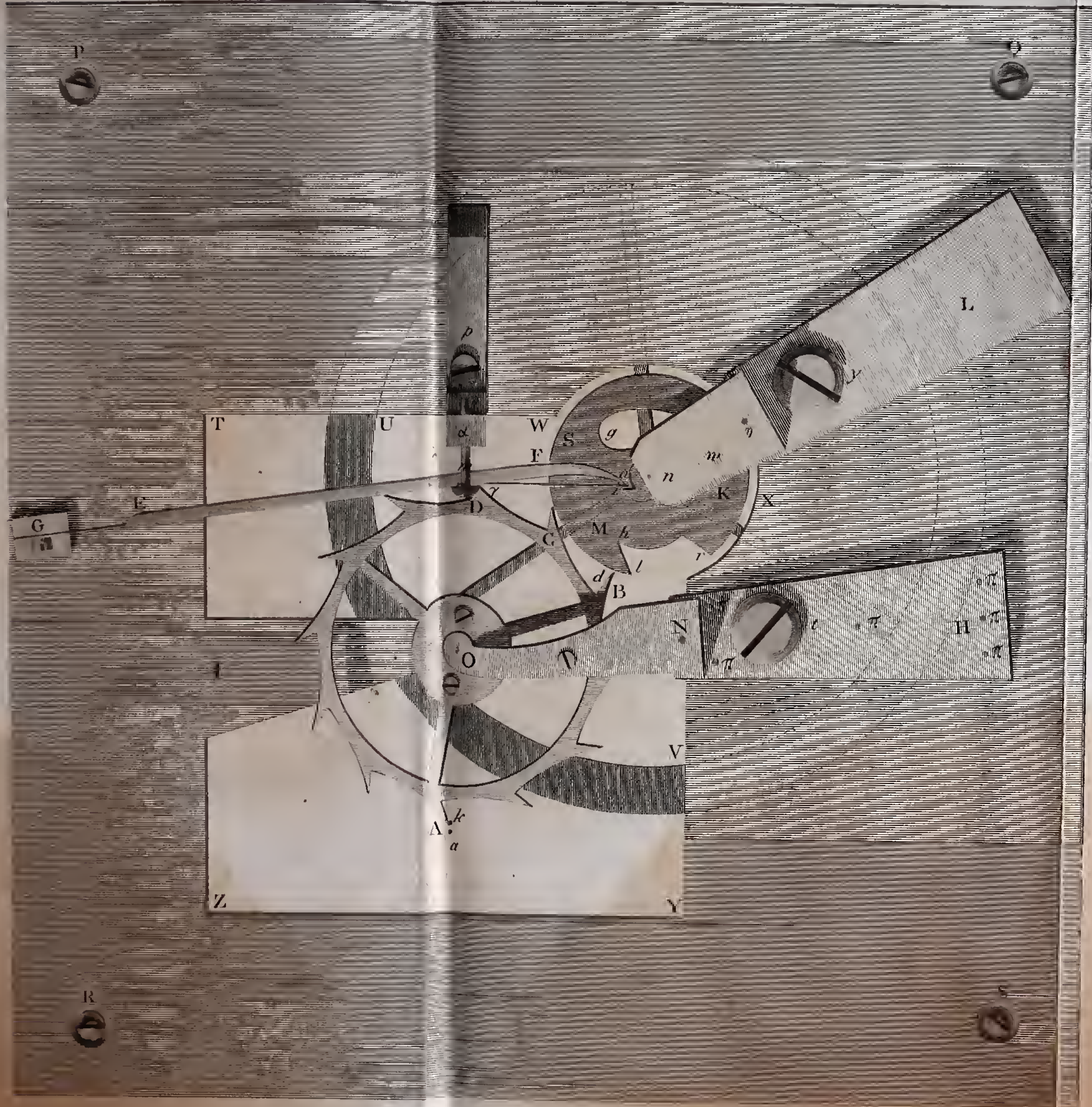


Fig. 1.

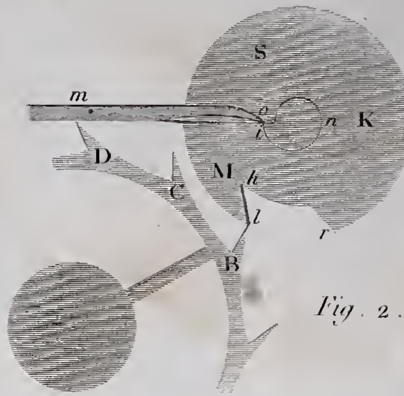
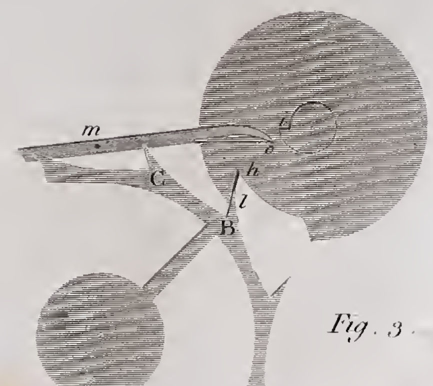


Fig. 2.



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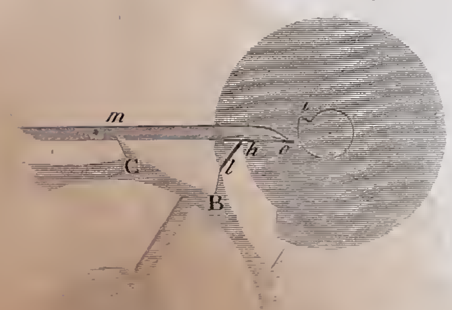

Fig. 4.

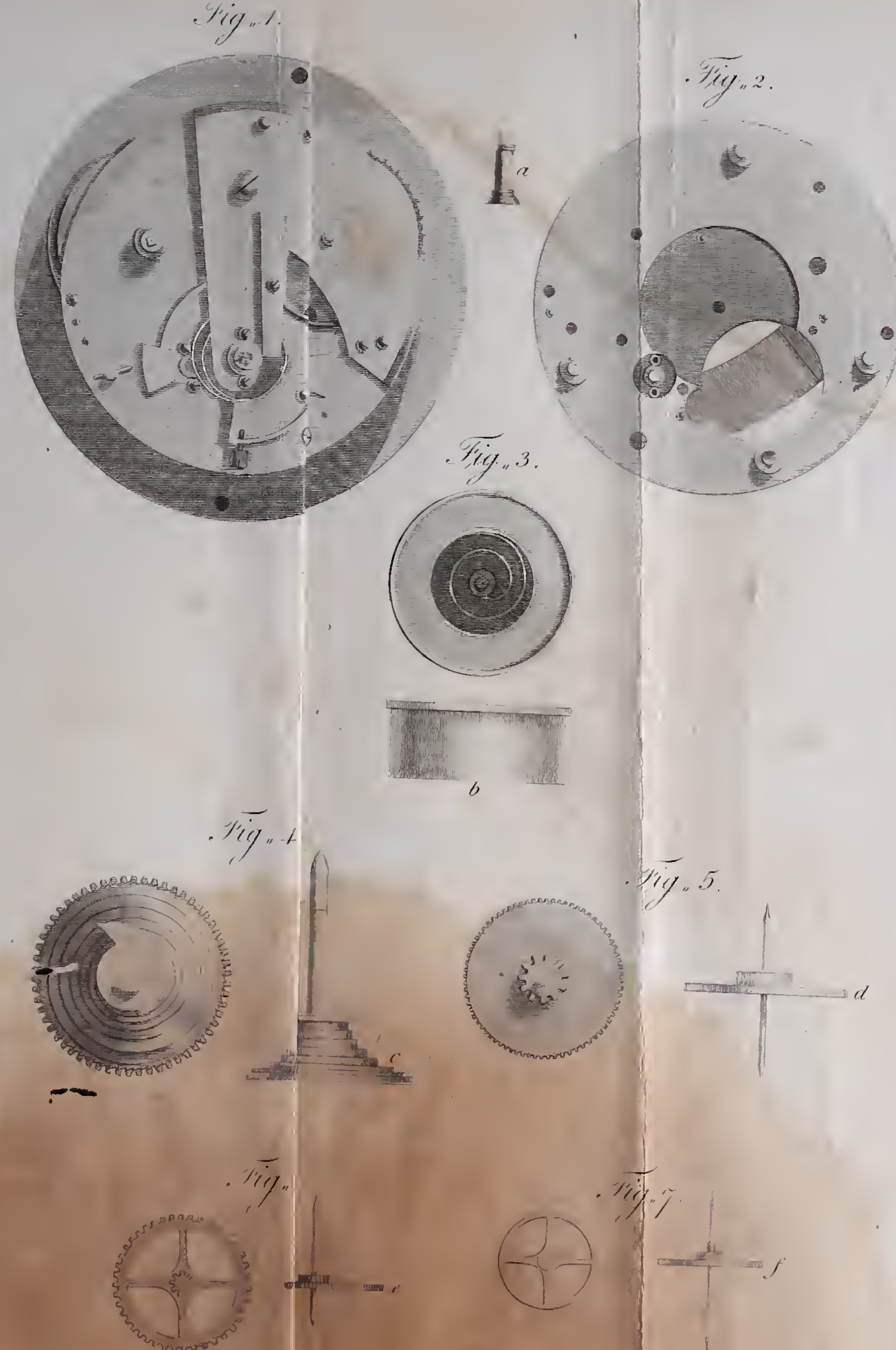
Fig. 1.
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Fig. 2.
Fig. 3.
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Fig. 4
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Fig. 5.
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Fig. 7
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From the Model of Mr. Arnold's Escapement.

Fig. 1.

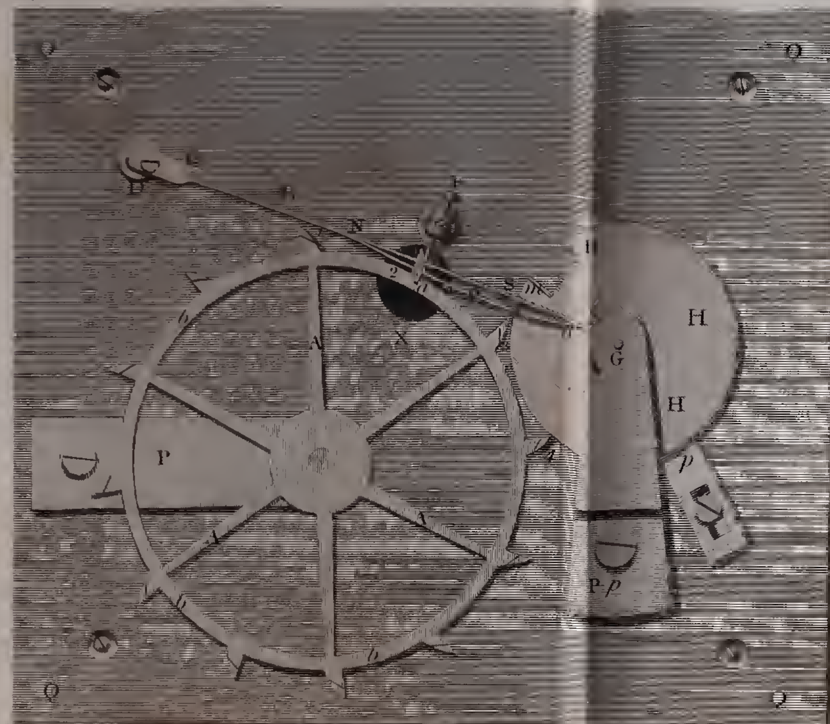
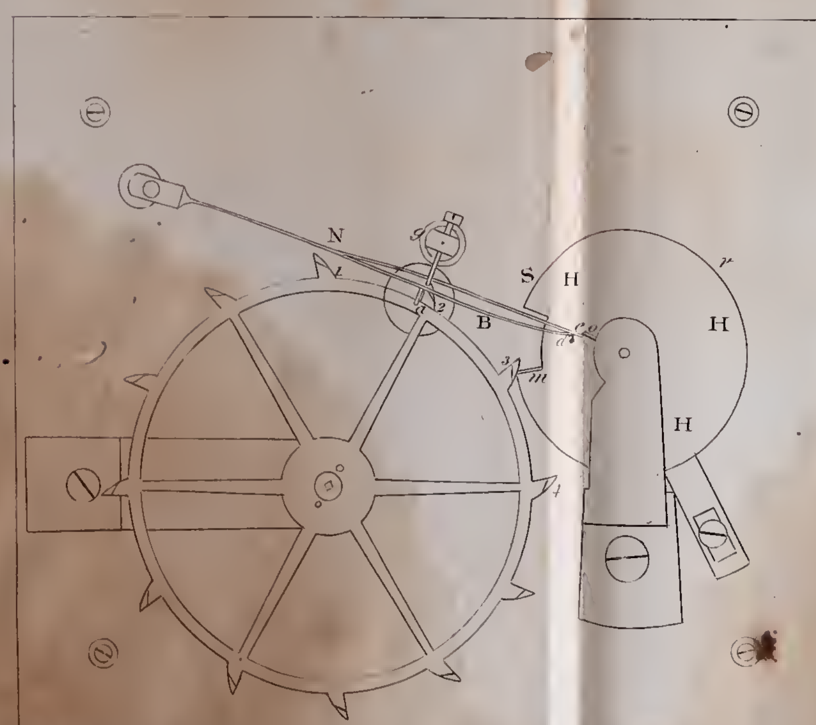


Fig. 2.



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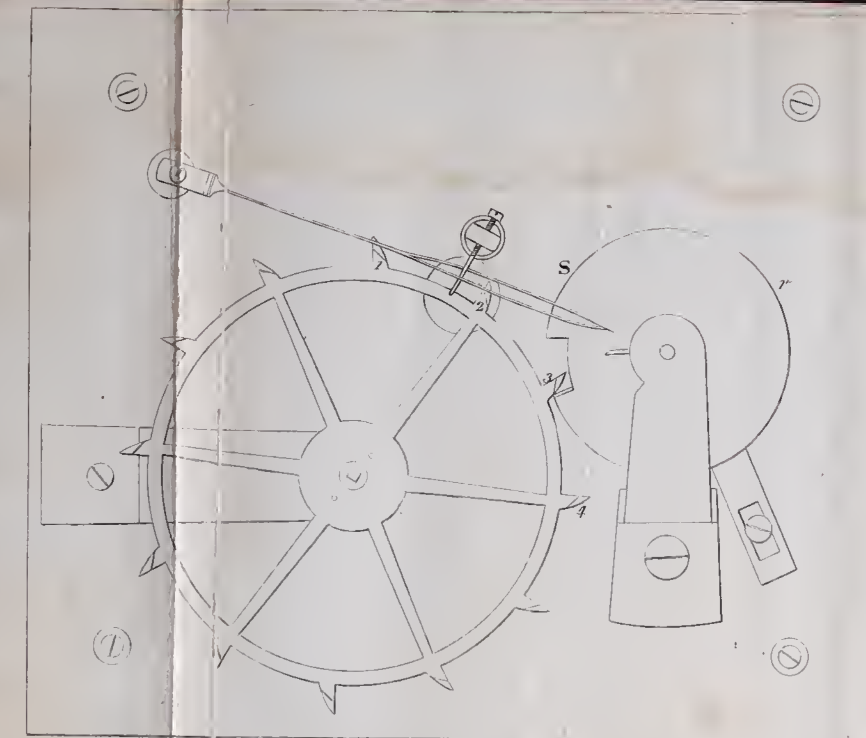

Fig. 4.

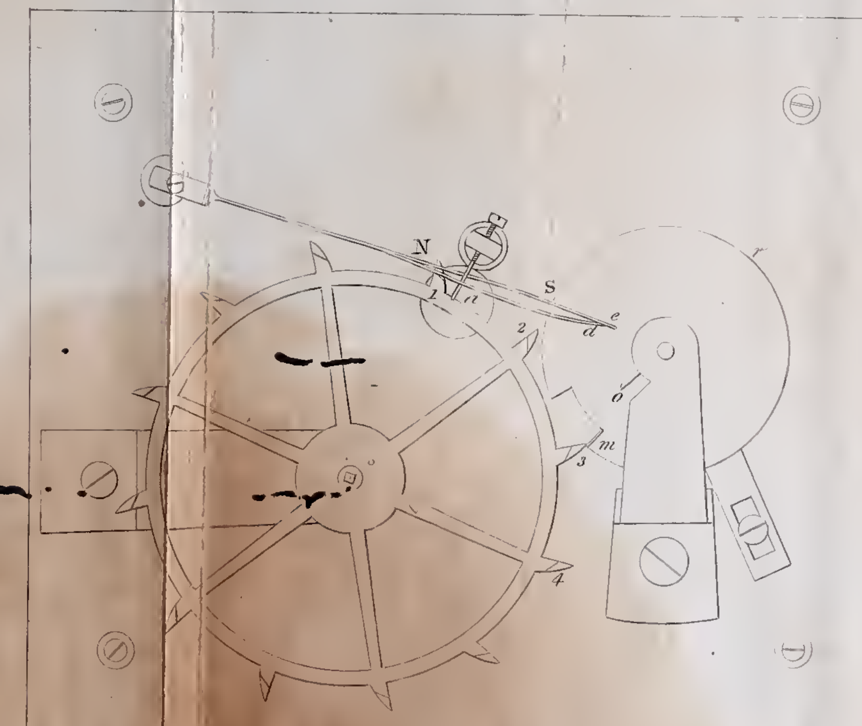

Fig. 5.